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**Vertical Accuracy Assessment Report
2006 LiDAR Bare-Earth Dataset for
Los Angeles Region – Imagery Acquisition Consortium (LAR-IAC)**

Date: October 26, 2006

References: A — Part 3: *National Standard for Spatial Data Accuracy (NSSDA)*, “Geospatial Positioning Accuracy Standards,” published by the Federal Geographic Data Committee (FGDC), 1998
B — Appendix A, *Guidance for Aerial Mapping and Surveying*, “Guidelines and Specifications for Flood Hazard Mapping Partners,” published by the Federal Emergency Management Agency (FEMA), April 2003
C — *Guidelines for Digital Elevation Data*, Version 1.0, published by the National Digital Elevation Program (NDEP), May 10, 2004
D — *ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data*, published by the American Society for Photogrammetry and Remote Sensing (ASPRS), May 24, 2004
E — Appendix F, *Acceptance Criteria for DTMs and Contours*, “Quality Plan for Los Angeles County,” Version 1.2, 2005
F — NOAA Technical Memorandum NOS NGS-58, “Guidelines for Establishing GPS-Derived Ellipsoid Heights (Standards: 2 cm and 5 cm), November, 1997.

Background

The National Standard for Spatial Data Accuracy (NSSDA), Reference A, identifies standard methodology for testing and reporting the accuracy of digital geospatial data; the NSSDA assumes that all errors follow a normal error distribution where root-mean-square-error (RMSE) procedures apply. FEMA guidelines, Reference B, implement the NSSDA and further recommend the survey of 20 QA/QC checkpoints in each major land cover category representative of the area being tested, with a minimum of three land cover categories (i.e., minimum 60 checkpoints). References C and D provide an alternative whereby errors in vegetated areas are not assumed to follow a normal error distribution (as demonstrated to be true in many States); References C and D also recommend a minimum of 60 checkpoints, with up to 100 points preferred. For the LAR-IAC Quality Plan, Reference E, five land cover categories were determined by Dewberry to be representative of floodplains within Los Angeles County. For one of these land cover categories (built-up areas), 39 QA/QC checkpoints were randomly selected from survey points provided by LAR-IAC. For the remaining four land cover categories, 20 checkpoints each were surveyed by Towill, Inc. consistent with procedures in Reference F. A total of 119 QA/QC checkpoints (80 from Towill and 39 from LAR-IAC) were used for this assessment as summarized below.

Dewberry’s LiDAR accuracy assessment for LAR-IAC was performed in accordance with the two methods now used by the LiDAR industry. The original method (References A and B) assumes all errors follow a normal error distribution, and the newer method (References C and D) assumes that LiDAR errors in some land cover categories may not follow a normal error distribution. Comparisons between the two methods help determine the degree to which *systematic errors* may exist in Los Angeles County’s five major land cover categories: (1) open terrain, (2) weeds and crops, (3) scrub and bushes, (4) forests, and (5) built-up areas. When a LiDAR bare-earth dataset passes testing by both methods, compared with criteria specified in Reference E, the dataset clearly passes all vertical accuracy testing criteria for a digital terrain model (DTM) suitable for generation of 2-ft contours in Los Angeles County. The relevant

criteria from Reference E are summarized in Table 1. Criteria in yellow refer to references A and B (NSSDA and FEMA); criteria in green refer to references C and D (NDEP and ASPRS).

Table 1 — DTM Acceptance Criteria from the Quality Plan for Los Angeles County

Quantitative Criteria	Measure of Acceptability
RMSE _z = NSSDA vertical accuracy statistic at 68% confidence level (1.0 x RMSE _z)	0.60 ft for all land cover categories combined
Accuracy _z = NSSDA vertical accuracy statistic at the 95% confidence level (1.96 x RMSE _z)	1.19 ft (RMSE _z x 1.9600) for all land cover categories combined
Fundamental Vertical Accuracy (FVA) in open terrain only = 95% confidence level	1.19 ft (RMSE _z x 1.9600) for open terrain only
Supplemental Vertical Accuracy (SVA) in individual land cover categories = 95% confidence level	1.19 ft (based on 95 th percentile per category; this is a target value only, not mandatory)
Consolidated Vertical Accuracy (CVA) in all land cover categories combined = 95% confidence level	1.19 ft (based on combined 95 th percentile)

Vertical Accuracy Testing in Accordance with NDEP and ASPRS Procedures

References C and D specify the mandatory determination of Fundamental Vertical Accuracy (FVA) and the optional determination of Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). FVA determines how well the LiDAR sensor performed in category (1), open terrain, where all errors are presumed to be random; whereas SVA determines how well the vegetation removal algorithms worked in land cover categories (2), (3) and (4) where LiDAR elevations are often higher than surveyed elevations, and how much the LiDAR penetrated into asphalt in land cover category (5) where LiDAR elevations are often lower than surveyed elevations if acquired when asphalt is hot.

FVA is determined with check points located only in land cover category (1), open terrain (grass, dirt, sand, and/or rocks), where there is a very high probability that the LiDAR sensor will have detected the bare-earth ground surface and where random errors are expected to follow a normal error distribution. The FVA determines how well the calibrated LiDAR sensor performed. With a normal error distribution, the vertical accuracy at the 95% confidence level is computed as the vertical root mean square error (RMSE_z) of the checkpoints x 1.9600, as specified in Appendix 3-A of the National Standard for Spatial Data Accuracy (NSSDA), FGDC-STD-007.3-1998. For Los Angeles County, the FVA standard is 1.19 feet (ft) at the 95% confidence level, equivalent to the Accuracy_z required for 2 ft contours.

CVA is determined with all checkpoints in all land cover categories combined where there is a possibility that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution. CVA at the 95% confidence level equals the 95th percentile error for all checkpoints in all land cover categories combined. The CVA is accompanied by a listing of the 5% outliers that are larger than the 95th percentile; these are always the largest outliers that may depart from a normal error distribution.

SVA is determined separately for each individual land cover category, recognizing that the LiDAR sensor and post-processing may yield elevation errors that do not follow a normal error distribution, and where discrepancies can be used to identify the nature of systematic errors by land cover category. For each land cover category, the SVA at the 95% confidence level equals the 95th percentile error for all checkpoints in each individual land cover category. SVA statistics are calculated individually for open terrain, weeds and crops, scrub, forests, and built-up areas in order to facilitate the analysis of the data based on each of these land cover categories that exist within Los Angeles County. The SVA criteria in

Table 1 are target values only and are not mandatory; it is common for some SVA criteria to fail individual target values, yet satisfy the mandatory CVA criterion.

The primary Quality Assurance/Quality Control (QA/QC) steps used by Dewberry were as follows to test the vertical accuracy of LiDAR bare-earth DTMs provided by Infotech:

1. Figure 1 shows the location of the QA/QC checkpoints within Los Angeles County, symbolized to reflect the five land cover categories used. However, because a checkpoint in one land cover category was allowed to be near another checkpoint, provided it is in a different land cover category, several of the symbols for the different land cover categories overlay each other and are not individually visible.
2. Next, Dewberry interpolated the bare-earth LiDAR DTM to provide the z-value for each of these checkpoint coordinates.
3. Dewberry then computed the associated z-value differences between the interpolated z-value from the LiDAR data and the ground truth survey checkpoints and computed the FVA, CVA and SVA values.
4. The data were analyzed by Dewberry to assess the quantitative quality of the data. The review process examined the various accuracy parameters as defined by NDEP and ASPRS guidelines. Also, the overall descriptive statistics of each dataset were computed to assess any trends or anomalies. The following tables, graphs and figures illustrate the data quality.

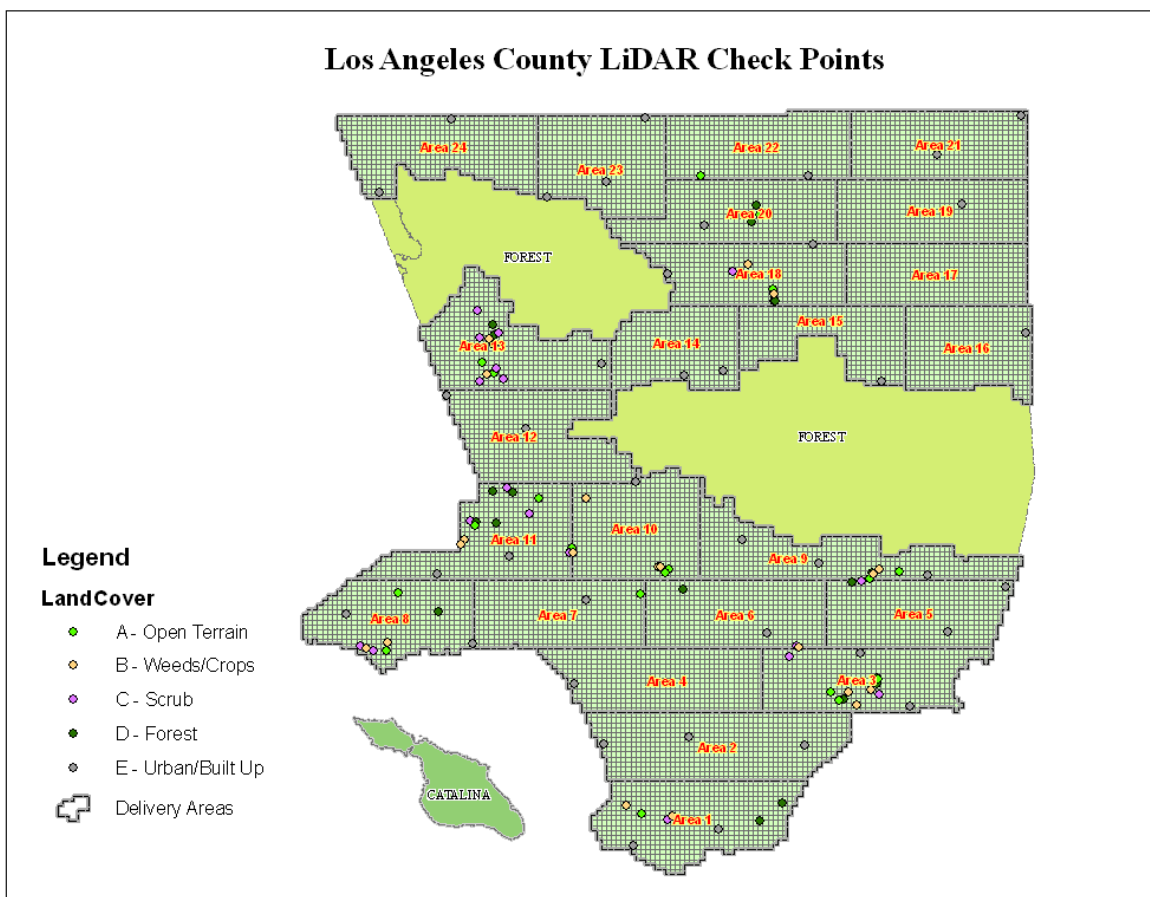


Figure 1 — Location of QA/QC Checkpoints

Table 2 summarizes the vertical accuracy by fundamental, consolidated and supplemental methods:

Table 2 — FVA, CVA and SVA Vertical Accuracy at 95% Confidence Level

Land Cover Category	# of Points	FVA Fundamental Vertical Accuracy Spec = 1.19 (ft)	CVA Consolidated Vertical Accuracy Spec = 1.19 (ft)	SVA Supplemental Vertical Accuracy Target = 1.19 (ft)
Total Combined	119		0.91 ft	
Open Terrain	20	0.65 ft		0.70 ft
Weeds/Crops	20			0.85 ft
Scrub	20			0.87 ft
Forest	20			1.15 ft
Built Up	39			0.48 ft

The LiDAR data of Los Angeles County meets all mandatory and target specifications as per the following vertical accuracy tests.

Compared with the 1.19 ft FVA specification, FVA tested 0.65 ft at the 95% confidence level in open terrain, based on $RMSE_z \times 1.9600$. The NSSDA specifies that vertical accuracy at the 95% confidence level equals $RMSE_z \times 1.9600$; the NDEP and ASPRS state that this method is valid only when random errors follow a normal error distribution, as in open terrain.

Compared with the 1.19 ft CVA specification, CVA tested 0.91 ft at the 95% confidence level in open terrain, weeds and crops, scrub, forests, and built-up areas combined, based on the 95th Percentile. NDEP and ASPRS guidelines specify that vertical accuracy at the 95% confidence level equals the 95th percentile when random errors may not follow a normal error distribution, as in vegetated areas. Table 3 lists the 5% outliers larger than the 95th percentile (0.91 ft).

Table 3 — 5% Outliers Larger than 95th Percentile

Land Cover Category	Elev. Diff (ft)	Only one error (-1.23 ft) was larger than the CVA standard (1.19 ft) which permits up to 5% of the checkpoints, normally 6 of 120, to be larger than 1.19 ft.
Weeds/Crop	1.00	
Scrub	1.08	
Forest	-1.23	
Forest	-1.15	
Forest	-1.08	
Forest	-0.98	

Compared with the 1.19 ft SVA target values, SVA tested 0.70 ft at the 95% confidence level in open terrain; 0.85 ft in weeds and crops; 0.87 ft in scrub; 1.15 ft in forests; and 0.48 ft in built-up areas, based on the 95th Percentile. These values exceed all of their target values.

Figure 2 illustrates the SVA by specific land cover category. Figure 3 illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data by specific land cover category and sorted from lowest to highest. Whereas 95% of the checkpoints should be accurate within ± 1.19 ft as shown in Figure 3, all but one of the checkpoints met this criterion. There is no significant bias in any of the land cover categories except for scrub where there is a positive bias and skew. In other datasets evaluated by Dewberry, the scrub category has often been more skewed than other land cover categories, so this is not unusual.

95th Percentile by Land Cover Type

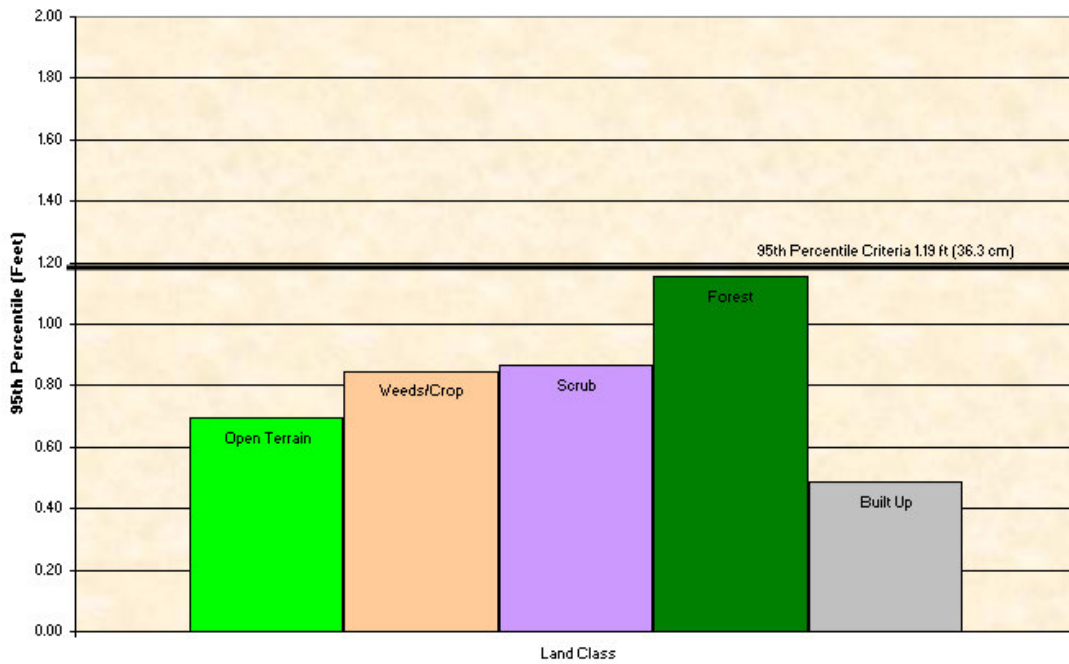


Figure 2 — Graph of SVA Values by Land Cover

95th Percentile Vertical Accuracy Criteria

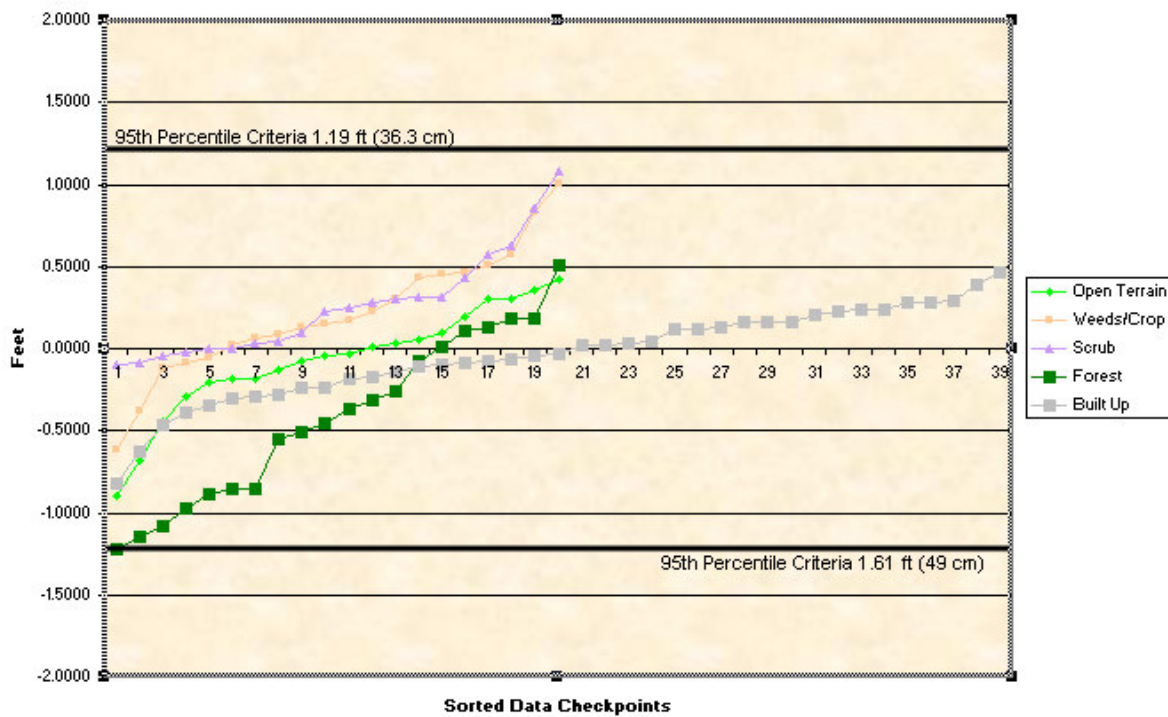


Figure 3 — Magnitude of Elevation Discrepancies, Sorted from Largest Negative to Largest Positive

Vertical Accuracy Testing in Accordance with NSSDA and FEMA Procedures

The original NSSDA and FEMA guidelines were both published before it was recognized that LiDAR errors do not always follow a normal error distribution. Future changes to these FGDC and FEMA documents are expected to follow the lead of the NDEP and ASPRS. Nevertheless, to comply with FEMA's current guidelines in Reference C, RMSE_z statistics were computed in all five land cover categories, individually and combined, as well as other statistics that FEMA recommends to help identify any unusual characteristics in the LiDAR data. These statistics are summarized in Figures 4 and 5 and Table 4 below, consistent with Section A.8.6.3 of Reference B.

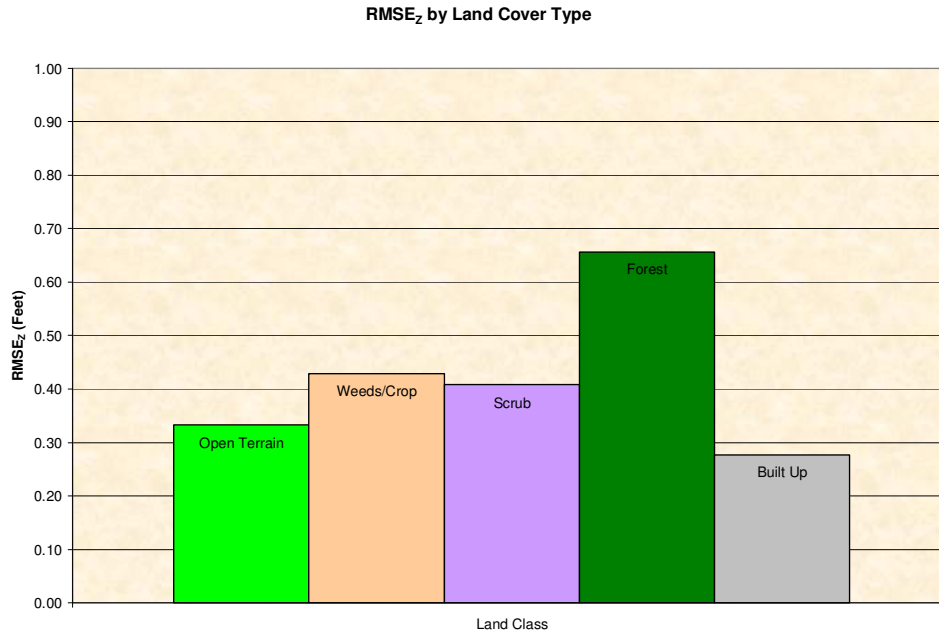


Figure 4 — RMSE_z statistics by Land Cover Category

Table 4 — Overall Descriptive Statistics by Land Cover Category and Consolidated

Land Cover Category	RMSE _z (ft)	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	# of Points	Min (ft)	Max (ft)
Consolidated	0.42	-0.02	0.02	-0.48	0.42	119	-1.23	1.08
Open Terrain	0.33	-0.07	-0.04	-0.85	0.33	20	-0.90	0.42
Weeds/Crops	0.43	0.21	0.16	0.01	0.39	20	-0.62	1.00
Scrub	0.41	0.26	0.24	1.15	0.32	20	-0.10	1.08
Forest	0.66	-0.42	-0.41	0.03	0.52	20	-1.23	0.51
Built Up	0.28	-0.04	-0.04	-0.64	0.28	39	-0.82	0.47

Figure 5 illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the LiDAR triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -1.23 ft and a high of +1.08 ft, the histogram shows the degree to which discrepancies are skewed compared with a “bell curve,” with mean of zero, if the data were truly normally distributed. This histogram is typical of all LiDAR datasets evaluated by Dewberry for hundreds of counties nationwide.

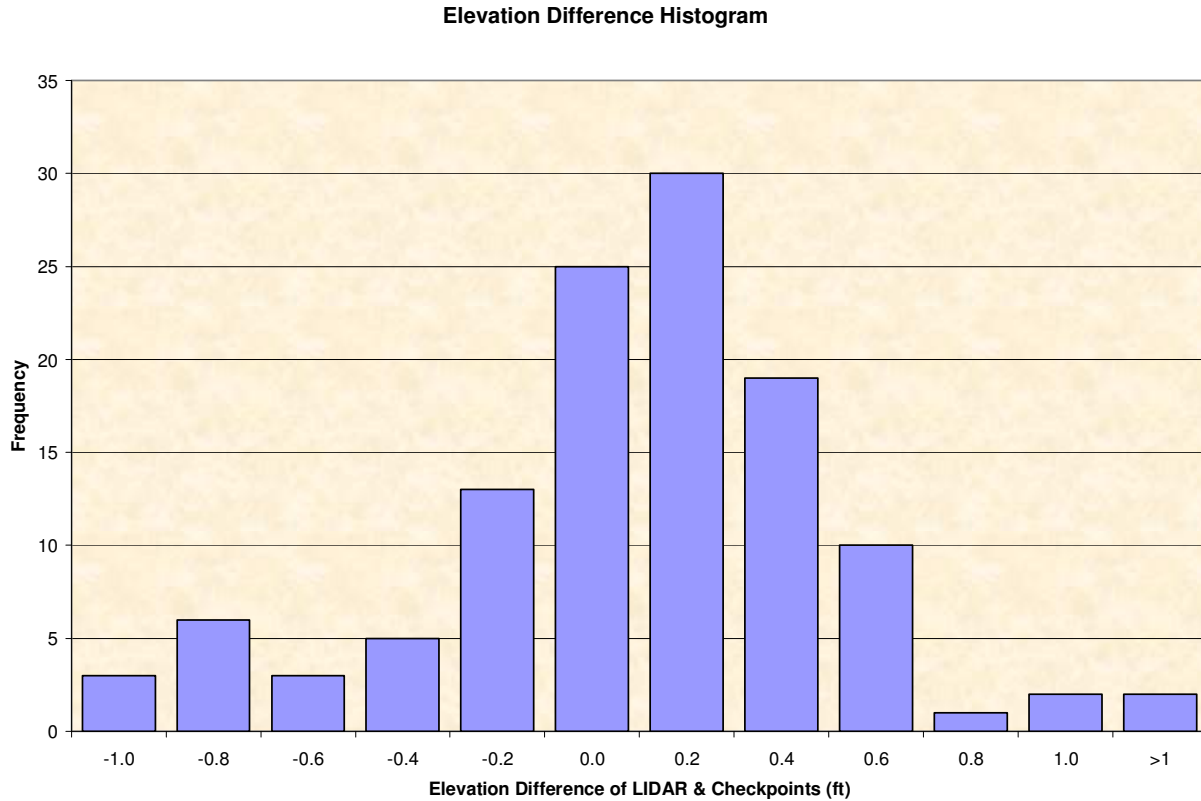


Figure 5 — Histogram of Elevation Discrepancies within 0.2 ft Bands

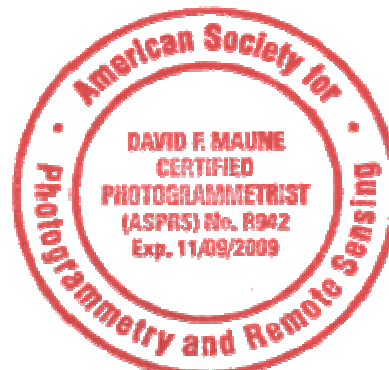
Conclusions

Based on the vertical accuracy testing methodology and the number of checkpoints, the LiDAR data have excellent vertical accuracy and are well suited for production of 2 ft contours.

- Based on NSSDA and FEMA methodology: Tested 0.82 ft vertical accuracy at 95% confidence level (Consolidated $RMSE_z \times 1.9600$).
- Based on NDEP and ASPRS methodology: Tested 0.91 ft vertical accuracy at 95% confidence level (Consolidated Vertical Accuracy).
- These values greatly exceed the 1.19 ft vertical accuracy standard required for digital elevation data to support the generation of 2 ft contours.

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I hereby state that I have reviewed this document and find it to be in conformance with the requirements of the 2006 Professional Land Surveyors Act (Sections 8700 to 8805 of the Business and Professions Code) of the State of California.

A handwritten signature in black ink, appearing to read "Bruce F. Hunsaker", with a long horizontal stroke extending to the right.

Bruce F. Hunsaker, PLS

